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Measurement and analysis of magnetic fields from welding processes

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Measurement and analysis of magnetic fields from welding processes

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Welding is ubiquitous in manufacturing and fabrication industries using relatively high currents that generate significant magnetic fields around cables, work pieces and electrodes. European Directive (EC/40/2004) on the restriction of exposures of workers to electromagnetic fields (EMFs) will be implemented in UK legislation by April 2008.

Basic field measurements are compared to reference levels at various frequencies, as recommended by the International Commission for Non-Ionizing Radiation Protection (ICNIRP). Worker exposures exceeding the reference levels are not necessarily harmful, but indicate the need for more detailed assessments to check compliance with basic restrictions.

Measured fields are compared with the effective reference levels, taking account of the frequency components (harmonics) of the fields. Measurements were made for three resistance welding machines and five arc welding power sources. General conclusions were that the ICNIRP reference levels are exceeded at distances of less than 30 cm from the electrodes of resistance welding machines and at distances less than 20 cm from the cables of some arc welding equipment, depending on the welding current.

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EXECUTIVE SUMMARY

Background

Welding is used widely in heavy and light industry and around 2.3 million people are employed in metal goods, engineering and vehicle production in the UK. Workers in the fabrication industry are exposed to magnetic fields from the welding processes. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published guidelines on limits of exposure to static magnetic fields in 1994 and on limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz) in 1998. The guidelines advise basic restrictions to provide protection against the established adverse health effects of exposure. Reference levels are also given for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Compliance with the reference levels ensures compliance with the relevant basic restrictions, however, the reference levels are not limits and if they are exceeded, it does not necessarily follow that the basic restrictions will also be exceeded. Evidence exists that (ICNIRP) reference levels may in some cases be exceeded for welding processes. There are a wide variety of welding processes, but the two most commonly used in industry, arc and resistance welding, are probably the ones which result in the greatest exposures. The aim of this report is to provide a satisfactory understanding of the magnetic fields which are present in the immediate spatial environment around a number of typical welding processes.

This work was funded by the Health and Safety Executive (HSE) and was to inform negotiations on the European Directive on restructing exposures of workers to electromagnetic fields (EC/40/2004) and its future implementation into UK law. This Directive will be transposed into UK national legislation by April 2008. The ICNIRP reference levels and basic restrictions equate to action values and exposure limit values respectively in the Directive.

Objectives

- To carry out a comprehensive review of published information and other sources of information on magnetic fields associated with arc and resistance welding processes.
- To carry out an analysis of the spatially varying magnetic field levels to which welders are exposed from arc and resistance welding.
- To tabulate for HSE, magnetic field data from a range of welding processes examined.

Work Carried Out

Magnetic field measurements have been made for a number of different types of resistance and arc welding equipment and processes. Tests were carried out at typical operating conditions for the equipment and measurements were recorded at varying distances away from the equipment and cables.

The data collected has been analysed and tabulated with the significant frequency components of the magnetic field individually identified. The frequency components have then been summed and compared to the effective ICNIRP reference levels in accordance with ICNIRP procedures.

The following resistance welding equipments were tested:

- Single phase resistance welding machine.
- Three phase resistance welding machine.
- Medium frequency inverter resistance welding machine.
- Single phase resistance welding machine with a “kickless cable”.

The following arc welding equipments were tested:

- AC conventional arc welding transformer.
- DC thyristor arc welding power source.
- DC inverter arc welding power source.
- AC “square wave” inverter arc welding power source.
- DC pulsed MIG/MAG inverter arc welding power source.

Conclusions

From a literature review and measurements made of magnetic fields in the vicinity of resistance and arc welding equipment the following conclusions are drawn.

1. A review of the literature indicates that ICNIRP reference levels for magnetic fields may be exceeded for both arc and resistance welding. However, in most cases a lack of experimental details and broadband measurements make it difficult to draw any significant conclusions from the data.
2. The magnetic field is made up of many harmonic components which need to be taken into account when making assessments against ICNIRP reference levels.
3. For resistance welding equipment the ICNIRP reference levels are exceeded in most cases at the position that the welder would normally stand, i.e. 30cm from the electrodes.
4. For single phase and medium frequency inverter resistance welding equipment, examined at a welding current of 15kA, the reference levels are unlikely to be exceeded at distances greater than 100cm from the electrodes.
5. The magnetic field around three phase equipment is generally less and the reference levels are unlikely to be exceeded at distances greater than 50 cm, for the equipment examined at a typical welding current of 15kA.
6. The magnetic field around a kickless resistance welding cable was found to be below the effective reference level at distances of 20cm or more.
7. Magnetic fields from arc welding are in general below the reference levels at distances of 20cm or greater, with some exceptions. It is therefore recommended that welders do not come into close proximity with welding cables wherever possible. Draping the cables over the shoulder or around the body should be avoided.
8. Recent developments in arc welding equipment, namely AC square wave and pulsed MIG/MAG, develop significantly higher magnetic fields and the effective reference levels may be exceeded.
9. Further investigation is required to assess whether the ICNIRP basic restrictions are also exceeded.

Recommendations

This work has indicated that the ICNIRP reference levels for magnetic fields are likely to be exceeded for many resistance welding machines at the position that the operator would normally stand. Also, for arc welding, particularly with modern AC square wave and pulsed power sources the ICNIRP reference levels may be exceeded in some circumstances.

A more detailed investigation is required taking into account how the equipment may be used and it is recommended that the data obtained during this project is further analysed using modelling tehcniques to assess whether the ICNIRP basic restrictions are also exceeded.

Guidance is required from equipment manufacturers to assist fabricators in adopting working practices that will not expose welders to magnetic fields in excess of the ICNIRP basic restrictions.

1. INTRODUCTION

Welding is used widely in heavy and light industry and around 2.3 million people are employed in metal goods, engineering and vehicle production in the UK. Workers in the fabrication industry are exposed to magnetic fields from the welding processes. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published guidelines on limits of exposure to static magnetic fields in 1994 and on limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz) in 1998. The guidelines advise basic restrictions to provide protection against the established adverse health effects of exposure. Reference levels are also given for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Compliance with the reference levels ensures compliance with the relevant basic restrictions, however, the reference levels are not limits and if they are exceeded, it does not necessarily follow that the basic restrictions will also be exceeded. Evidence exists that (ICNIRP) reference levels may in some cases be exceeded for welding processes. There are a wide variety of welding processes, but the two most commonly used in industry, arc and resistance welding, are probably the ones which result in the greatest exposures.

The aim of this report is to provide a satisfactory understanding of the magnetic fields which are present in the immediate spatial environment around a number of typical welding processes.

Published information on magnetic field measurements for these welding processes is reviewed.

Measurements have been made on a number of arc and resistance welding equipments, covering the most widely used types of equipment and process variants. In each case the measurements have been carried out over a range of distances and the individual frequency components of the magnetic field have been calculated. These values have been compared to the ICNIRP reference levels.

This work was funded by the Health and Safety Executive (HSE) and was to inform negotiations on the European Directive on restricting exposures of workers to electromagnetic fields (EC/40/2004) and its future implementation into UK law. This Directive will be transposed into UK national legislation by April 2008. The ICNIRP reference levels and basic restrictions equate to action values and exposure limit values respectively in the Directive.

2. OBJECTIVES

- To carry out a comprehensive review of published information and other sources of information on magnetic fields associated with arc and resistance welding processes.
- To carry out an analysis of the spatially varying magnetic field levels to which welders are exposed from arc and resistance welding.
- To tabulate for HSE, magnetic field data from a range of welding processes examined.

3. LITERATURE REVIEW

3.1. ARC WELDING

3.1.1. Process and equipment

There are many different arc welding processes, using alternating current (AC), direct current (DC) and pulsed welding current. Most processes can be used either manually or mechanised. The most common are manual metal arc (MMA), metal inert gas (MIG) or metal active gas (MAG) and tungsten inert gas (TIG). Also there is plasma welding (and cutting) and submerged arc welding, which is usually mechanised.

The MMA welding process, which is the most widely used arc process, uses coated electrodes usually about 200-400mm long. The arc is struck between the end of the electrode and the component to be welded, melting the electrode into the joint. Each electrode takes typically 45-90 seconds to be consumed. The electrode must then be replaced for welding to continue. MMA is carried out with both AC and DC current, with a trend towards DC in recent years. Also, small inverter type power sources are becoming popular, particularly for hobby and maintenance use. The welding current depends on the size of the electrode and varies over the range 40-400A. The electrode holder is held in the welders hand and the cables are often draped over the shoulder or wound around the arm. Cable length of tens of metres may be used in construction and ship yards.

In the MIG/MAG process the electrode is replaced with a continuous wire which is fed through a torch, which may be held by the welder or attached to a robot arm. Welding can continue for several minutes, usually limited by the size of the component or the need for the welder to move position. MIG/MAG is predominantly DC although recently an AC process has been developed, but is not widely available. Also, the welding current may be pulsed at typically 10-150 Hz between a low background level (50A) and a higher peak value (typically 400-600A).

TIG welding is used primarily for welding precision components in stainless steels, nickel alloys and aluminium. The arc is struck between a non-consumable tungsten electrode and the component being welded. If a filler metal is required a wire is fed separately into the weld pool. TIG welding is carried out using DC, AC (30Hz – 300Hz) for aluminium and pulsed current (2Hz – 20kHz). Welding current typically ranges from 5A to 500A.

Submerged arc welding is a mechanised process similar to MIG/MAG welding except that the arc is buried (submerged) beneath a flux along the joint, rather than protected with a shielding gas. AC or DC is used at currents up to 1500A and higher. Up to five wires may be fed into the same weld pool.

Plasma welding is similar to TIG but the electrode is recessed within the torch and the arc plasma is constricted through a narrow orifice. Plasma which can be manual or mechanised is usually DC or pulsed and can also be used for cutting, if air is substituted for an inert gas.

Welding equipment varies in complexity between a simple transformer and a microprocessor controlled inverter power supply. Over the last twenty years or so the main developments have been in inverter technology to provide smaller and lighter power sources, with improved performance and energy efficiency. In an inverter power source the single or three phase main input is first rectified and then switched at high frequency through the power transformer. The secondary is then generally rectified to give a DC output, with a ripple at the switching frequency. Consequently although the output is nominally DC it may contain a high frequency ripple which will produce a magnetic field at that frequency. Switching frequencies have increased from a few kiloHertz to up to 100kHz today.

Also, pulsed welding has become applied increasingly, particularly for MIG welding, for improved arc characteristics and reduced spatter.

3.1.2. Published papers

There are a small number of papers containing measurements of magnetic fields carried out for arc welding. Perhaps the most comprehensive is the study carried out by Stuchly and Lecuyer (1989) the results of which were reproduced in the National Radiological Protection Board (NRPB) report R265 by Allen (1994). Measurements were made 10 cm away from the operator's body. Magnetic fields up to 200 µT, 300 µT and 400 µT were measured at the welders head, chest and waist respectively and up to 1000 µT at the welders hand, due to holding the welding torch or electrode holder.

Measurements were also made at 10 cm away from the welding cables. However these results are confusing as they do not appear to correlate with the measurements carried out adjacent to the operators body. Furthermore, there is no correlation with the welding current stated. This is believed to be because the stated currents are the maximum rated welding currents of the power sources, rather than the actual welding currents used. The maximum magnetic field measured 10 cm from the welding cable was in excess of 1256 µT, which is about three times the ICNIRP reference level at 60Hz.

All the measurements were the rms at the frequency of the strongest field, which in most cases was observed to be 60Hz, although it was noted that some equipment produced the strongest field at 120Hz or 180 Hz.

Allen (1994) also stated some measurements were carried out by the NRPB on a TIG welder. Magnetic fields of 100-200 µT were measured at the operators position, 100 µT close to the power supply and 1000µT at the surface of the welding cable. No information was provided on welding current or whether the equipment was AC or DC.

In a study of electrical workers, Bowman et al (1988) took spot measurement at extremely low frequency (ELF) below 100Hz, adjacent to eight TIG welders. The magnetic fields measured were relatively low compared to those reported by other researchers at 2.4-9.0 µT (mean) for AC TIG and 0.4-1.6 µT (mean) for DC TIG. No values for the welding currents were given.

Skotte and Hjollund (1997) assessed exposure to ELF magnetic fields of welders and other metal workers and compared exposure from different welding processes. Measurements were carried out over the working day using personal exposure meters attached to a belt. Some measurements were also made for short durations 1cm away from the welding cables.

Typical instantaneous magnetic fields of 100 µT were measured for AC MMA welding and 10 µT for DC MIG/MAG welding. For full-shift welders the average work day mean was found to be 21.2 µT for MMA welders and 2.3 µT for MIG/MAG welders. This equates to average exposures over the actual welding time of 65 µT for MMA and 7 µT for MIG/MAG.

Hall probe measurements (DC) taken 1cm from the welding cables gave 5 mT for submerged arc welding and 0.9 to 1.9 mT for MIG/MAG.

3.1.3. Current research

To the authors knowledge, the only organisation, apart from TWI, currently carrying out magnetic field measurements on arc welding is the National Institute for Working Life, Umeå, Sweden. They have taken measurements on MIG and an MMA inverter power source.

Some welding equipment manufacturers are starting to take measurements to support the European Committee for Electrotechnical Standardization (CENELEC) standardisation. The European Commision has issued mandates for standards to support the Low Voltage Directive (LVD) and Radio and Telecommunications Terminal Equipment (R&TTED) Directives (M/305) and for workers exposure to electromagnetic fields (M/351).

3.2. RESISTANCE WELDING

3.2.1. Process and equipment

Resistance welding is the most widely used welding process for joining sheet metal components in the mass production industries. The workpiece, consisting of two sheets of metal, face to face, is placed between two electrodes and a current is passed between them. Localised resistance heating produces a fused nugget. For spot welding the electrodes are cylindrical and a weld is made at a single point. In seam welding the workpiece is passed between two wheels as electrodes and a continuous or pulsed current produces a weld.

Most spot welding equipment currently in production works at mains frequency single phase AC. The heat input to the weld is controlled by the welding current, which is at many thousands of amps, and the weld time, usually expressed as a number of cycles. The current is controlled by the conduction angle of the thyristors. For lower currents the current flows for a smaller percentage of the half cycle.

Increasingly DC is being used which improves the power factor and balances the power demand between three phases. Also, as with arc welding, high (medium) frequency inverter supplies are increasingly being used. Switching frequencies at around (600-1200Hz) are lower than for arc welding.

Manual resistance welding is carried out either with the welder holding the gun or moving a component between the fixed electrodes of a pedestal welder. These days manual welding guns usually have built in transformers and are fed from the primary supply, but alternatively a remote transformer supplies secondary current to the gun.

3.2.2. Published papers

The study carried out by Stuchly and Lecuyer (1989), the results of which were reproduced in the NRPB report R265 by Allen (1994), included measurements for resistance welding. As with arc welding the results are confusing because maximum rather than measured welding currents were stated. Resistance welding equipment was described as spot welders. Measurements were made 10 cm from the welders body for the head, chest, waist, gonads, hands and legs, but no information was provided on the welders' position with respect to the resistance welding equipment. Highest field measurements were obtained from a portable spot welder giving 438μT, 625μT and 1000μT for the waist, gonads and hand respectively. This paper suggests that with resistance welding the harmonic content of the fields at power frequencies was lower than for arc welding.

Cooper (2002) presents results showing considerable harmonic content up to the 13 harmonic for resistance welding equipment. This was attributed to the "pulsed" AC operation. An effective reference level of 240μT was calculated (Chadwick, 1998) compared to the level of 500μT for a pure 50Hz waveform. The effective reference level was derived from the harmonic content at the waveform, by summing the quotients of the individual reference levels.

Cooper collated results from a considerable number of measurements carried out by or on behalf of the NRPB. Measurements were generally taken at varying distances away from and at the same height as the electrodes. Some measurements were taken at head height. Static magnetic fields of 30mT at

5cm and 10mT at 20 cm were measured for a DC welder at 14.1kA. For a high frequency welder at 8kA, the magnetic field was only 0.2mT where the operator would be situated.

Measurements of time varying magnetic fields showed that for some equipment and operators positions, the ICNIRP reference levels can be exceeded. At locations where the operators head or trunk may be exposed to these levels there is a possibility that the basic restrictions may be exceeded. Measurements are compared to calculate an effective reference level based on the harmonic components of the fields. The highest field measured was 9mT at 15 cm from a projection welder. Even at 100cm the field was measured at 1.52mT compared to an effective reference level of 0.23mT. Measurements taken at the position of the torso and head for a number of equipments exceeded the effective reference level. Measurements typically ranged between 0.2mT and 1.0mT but as high as 3.6mT in one case, 30cm from a spot welder.

Measurements carried out by Silny et al (2001) also indicate that the reference levels may be exceeded in the proximity of resistance welding equipment. Measurements were made for a capacitor discharge and a rectified current resistance welder. Magnetic fields between 20µT and 700µT were measured.

Doebbelin et al (2002) investigated the output and magnetic fields from a DC high frequency resistance welder, operating at 1kHz. The fundamental components of the field consisted of both 2kHz ripple and 300Hz from the rectified AC. Measurements and calculations determined that the permissible minimum distance away from the electrodes was 30cm. This work is supported by Nadeem et al who modelled the induced body current for a 3D human model. At 34 cm away from the machine it was found that the induced current density was $7mA/m^2$ which is below the ICNIRP basic restriction.

3.2.3. Current research

To the authors knowledge, work is continuing at Otto-von-Guericke University Magdeburg and tests are being carried out by equipment manufacturers to support CENELEC standardisation. The European Commission has issued mandates for standard to support the LVD and R&TTED Directives (M/305) and for workers exposure to EMF (M/351).

3.3. SUMMARY

A review of the literature indicates that the ICNIRP reference levels for magnetic fields may be exceeded for both arc and resistance welding. Magnetic fields of up to 400µT for arc welding and about 4000µT for resistance welding have been measured close to the operators body. In arc welding, it is common for the operator to be in contact with the welding cable for which fields up to 5000µT have been measured.

Unfortunately, due to a lack of experimental details it is difficult to interpret many of the measurements and vital information such as welding current and measurement distance are either absent or incorrectly recorded.

Some studies have indicated that the magnetic field is made up of many harmonic components, but most measurements have been broadband over the frequency response of the measuring equipment. A knowledge of the frequency components of the field is vital to make an accurate assessment of the field against the ICNIRP reference levels.

Consequently, detailed measurements of the amplitude and frequency spectrum of magnetic fields in the vicinity of welding equipment is required to make a true assessment of the fields to which welders are exposed.

4. PROGRAMME OF WORK

4.1. WELDING EQUIPMENT

The following resistance welding equipments were tested;

- R4 - single phase AC resistance welding machine.
- R10 - three phase DC resistance welding machine.
- R7 - medium frequency DC inverter resistance welding machine.
- R6 - single phase AC resistance welding machine with a “kickless cable”.

Each of these machines is a pedestal type resistance welder for which the operator feeds the material to be welded into the jaws. The electrodes then close onto the material and a weld is achieved by passing a high current through the material thickness. Resistance heating causes a “nugget” to form at the interface between the two sheets of material.

The following arc welding equipments were tested:

- A1 - AC conventional arc welding transformer.
- A2 - DC thyristor arc welding power source.
- A3 - DC inverter arc welding power source.
- A4 - AC “square wave” inverter arc welding power source.
- A5 - DC pulsed MIG inverter arc welding power source.

Each of these equipments was tested by manual welding. Cables to the workpiece and electrode holder or welding torch plug into the front of the equipment. Welding parameters are set using the controls on the front panel.

4.2. MEASURING EQUIPMENT

The magnetic inspection equipment used for the experimental surveys at TWI comprised the following functional elements:

- QinetiQ’s 3m Linear Plotter.
- Bartington 3 Axis Magnetometer.
- Combined 3 Axis Hall & Coil Sensor Head.
- COTS PC and Data Acquisition Card.

The QinetiQ linear plotter is a sensor platform that is moved along a longitudinal stainless steel lead-screw by a stepper-motor mounted at the end of the plotter. The magnetometer and the combined Hall & coil sensor head were mounted on the sensor platform of the linear plotter in as close proximity as possible, see Figure 1.

Due to the nature of the three types of magnetic sensor it was not feasible that they were mounted orthogonal to each other. To achieve this the centres of all nine sensors would have to intersect with one other. This would have required the manufacture of a highly complex sensor head, which was beyond the remit of this project

All of the nine sensors were connected to a bespoke interface module, which in the case of the magnetometer and the coil sensors simply made the connections to the data acquisition card. In terms of the Hall sensors the interface module provided both power to the Hall sensors and subsequent amplification/filtering of the Hall voltage produced in the presence of a magnetic field.

The interface module was in turn connected to a commercial data acquisition card housed in a standard IBM compatible PC.

4.2.1. Data acquisition

The voltages produced by the nine sensors on the instrumented head of the linear plotter were captured using the data acquisition card. Whilst the selected data acquisition card was the fastest multi-channel model available, in order to effectively measure the sensors across the required frequency range it was necessary to split the process into two separate stages. The first stage was to measure the Hall sensors and magnetometers and the second stage the coil sensors.

For each measurement data acquisition was either commenced manually, prior to beginning the welding process, or triggered directly from the welding machine being inspected. Data acquisition was stopped once a predefined time interval, generally two seconds, had elapsed. Finally the measured voltages were saved to an ASCII data file for subsequent data processing. An experimental log was made for each of the measurements taken including: file names, welding machine, welding current, sensor type and any other appropriate data.

4.2.2. Data processing and analysis

Processing of the acquired data was performed off-site, after each of the magnetic surveys was completed. In order to carry this out efficiently this was automated. Each of the data files generated during the survey was loaded and subsequently analysed.

Details of the analysis is given in the Appendix B and is summarised below:

- Measurements were checked for validity e.g. sensor not saturated.
- Voltage measurements were converted to magnetic fields.
- The magnitude of the magnetic fields in the frequency domain was calculated using Fast Fourmer Transforms and a frequency cut off applied based on the operating band width of the sensors.
- The resultant magnetic field was calculated by summing the three orthogonal axis for each sensor in quadrature.
- Data values above 10% at the ICNIRP reference level (at a particular frequency) were compiled to aid analysis.

4.3. EXPERIMENTAL DETAILS

4.3.1. Experimental procedures

Measurements of the magnetic field around equipments, cables and typical set-ups were made as appropriate. The linear plotter with sensor platform was positioned to enable measurements to be taken at selected intervals along the axis of interest. The linear plotter was positioned in the horizontal plane for measurement along the X and Z axes and supported vertically for measurements in the Y axis. For measurements in the horizontal plane the linear plotter was supported above the floor at the appropriate height by a combination of tables and wooden blocks as appropriate.

For each welding process and equipment, a series of measurements was taken for settings that would be typically used for the equipment or process.

For each measurement, the sensor platform was positioned with respect to the equipment by moving it along the linear plotter. Then a series of four welds was measured, two with the coils and alternatively, two with the combination of Hall sensor and magnetometer. At regular intervals background measurements with all three sensors were taken.

4.3.2. Resistance welding

For each resistance welding machine, R4, R10 and R7, measurements were made along three orthogonal axes. For the X and Z axes the origin was at the welding electrodes, as shown in Figure 2. For measurement in the vertical direction (Y), measurements were made at 30 cm in front of the electrodes, this being considered to be typical of where the operator would stand, with the origin in the horizontal plane of the electrodes. Measurements were made at distances between 10 cm and 200cm in the X and Z axes and for the Y axis, at the height of the electrodes (0cm) and 20cm and 50cm above and below that point, designated as positive and negative numbers respectively (i.e. 50, 20, 0, -20 and –50cm). Each resistance weld typically lasts for only a few tenths of a second, so for these tests a weld time of less than a second was chosen to give sufficient measurement time, but without overheating the equipment. Most of the measurements were carried out under short circuit conditions but a limited number of welding tests were made with R4. Small test samples 30mm x 30mm x 1mm and a longer plate 500mm x 500mm x 1mm with a number of welds were used for the tests. For the longer plate, a series of spot welds spaced 120mm apart were made.

For measurement taken from the "kickless cable" attached to R6, the cable was positioned horizontally for convenience, although in practice such cables would be suspended vertically from the welding transformer above. Measurements were made at distances of 10, 20 and 50cm from the cable, positioned 1, 1.5 and 2m along it's length as shown in Figure3.

For each equipment/measurement position, measurements were made for welding currents of nominally 5kA, 10kA and 15kA. However, not all welding currents were recorded for each position.

During the tests, measurements of the background magnetic field were made at regular intervals.

4.3.3. Arc welding

For each arc welding power source and process, measurements were made at distances of 10, 20 and 50cm away from the welding cable, using the configuration shown in Figure 4. The welding process, either MMA or MIG was chosen as appropriate. Some of the equipment used for the MMA welding trials is also capable of being used for the TIG welding process and hence the results would also be valid for this process, as the magnetic fields are mainly dependent on the welding current. This configuration (Figure 4) was chosen as that being proposed in draft standards for EMF measurements from welding installations as it is used to simulate the situation of a welding cable being draped over a part of the welder's body as happens typically in practice.

Initial measurements were made at 200A with an AC conventional arc welding transformer (A1). This basic power source although not manufactured today in significant numbers, is still widely used for MMA welding. These measurements were then repeated with two DC power sources, a DC thyristor arc welding power source (A2) and a DC inverter arc welding power source (A3).

Another series of tests was then carried out using the AC square wave power source (A4) also at 200A. This inverter based power source may be used for MMA and TIG welding. Unlike the single phase AC power source, this equipment generates an AC waveform by chopping the DC output to give a "square wave" AC output. The frequency of this output can be adjusted over a range of nominally 30Hz to 300Hz. For these tests three settings were chosen, minimum, maximum and a mid-point frequency set on an arbitary scale.

Additionally, MMA tests were carried out to assess the fields to which a welder may be exposed in a typical welding configuration, with the MMA process at 200A. A typical welding bay was set up with a power source and welding bench, positioned in front, 4 meters away. Welding cables laid across the floor connected the electrode holder and work bench to the power source. The linear plotter was positioned vertically in the place the welder would normally stand, next to the bench. For these tests the welder stood the other side of the bench, welding from the "wrong" side. The linear plotter and sensor platform was protected by a welding screen. The experimental set up is shown in Figure 5.

Measurements were made at a range of heights above the floor from 80cm to 180cm, to cover the position of the welder's head, neck and trunk. Three different cable configurations were investigated;

- Initially measurements were made with both cables across the floor, running beneath the position of the welder.
- Then the welding cable to the electrode was supported at 1.55 m above the ground, to simulate a welder draping the cable across his shoulder and the measurements were repeated.
- Finally the earth return cable on the floor was connected to a large metal plate, 2m by 1.4m by 20mm thickness, beneath the position where the welder would stand, to simulated him standing on a metal floor, e.g. the deck of a boat.

MAG welding was carried out with a DC pulsed MIG/MAG inverter power source (A5), using a carbon steel A18 filler wire with a commercially available shielding gas of argon, 15%CO_2, 2%O_2 as is typically used for standard fabrication. The power source that was used was pre-programmed with parameters based on the selection of wire feed speed. The following welding currents and metal transfer conditions were investigated.

- 150A dip transfer.
- 200A pulse transfer.
- 300A spray transfer.

These conditions are typical of what would be used in production for welding thin sheet steel, welding steel structures in all positions and high deposition (high productivity) welding of thick section steel in the flat position.

5. RESULTS

5.1. PROCESSING OF RESULTS

For each welding equipment and process the reduced data set has been tabulated showing the individual significant frequency components of the magnetic field. These values have been compared to the ICNIRP reference values, given in Table 6 of Appendix A, at the individual frequencies and the ratio of measured value (B_n) reference level(R_n) calculated. For compliance with ICNIRP reference levels, the summation of these individual contributions should be less than or equal to 1, i.e.

$$\sum_n \frac{B_n}{R_n} \leq 1$$

The results are summarised in the following tables and detailed in the subsequent clauses.

1. R4 single phase resistance welder.
2. R4 single phase resistance welder with test plates.
3. R10 three phase resistance welder.
4. R7 inverter resistance welder.
5. R6 single phase resistance welder with kickless cable.
6. MMA welding at 200A with A1, A2 and A3.
7. MMA/TIG welding, with AC square wave, inverter A4.
8. MMA welding at welder's position with A1 and A4.
9. MIG/MAG welding with A5.

5.2. R4 SINGLE PHASE RESISTANCE WELDER

A typical current waveform from the single phase welder is shown in Figure 6. The results, Table 1, show that the magnetic field from the single phase resistance welder is predominantly 50 Hz, but with significant harmonics up to 1150Hz (significant being in excess of 10 % of the reference level at that frequency). The highest magnetic field measured was 13.08 mT at 50Hz, 10 cm away from the electrode for a welding current of 15kA. Summing the frequency components at that position gave a resultant field over 60 times higher than the reference level.

The magnetic field at a typical operating position for manual welding of 30 cm in front of the electrode was found to be approximately between 3 and 11 times the reference level for a welding current of 15kA. Even at 5kA the reference level was exceeded by a factor of approximately 4.

Only at a distance of 1m in front of the electrodes was the summed magnetic field less than the reference level (0.68) at 15kA and at 1m to the side the reference level was still exceeded.

5.3. R4 SINGLE PHASE RESISTANCE WELDER WITH TEST PLATES

The measurements carried out when welding test coupons and a plate are given in Table 2. These results indicate that the magnetic field is reduced compared to a short circuit test at the same welding current of 10kA. In particular the harmonic components were found to be significantly less. This requires further investigation.

5.4. R10 THREE PHASE RESISTANCE WELDER

A typical current waveform from the three phase welder is shown in Figure 7. The results, Table 3, show that the magnetic field from the three phase resistance welder is predominantly 150 Hz, but with significant harmonics up to 1200Hz (significant being in excess of 10 % of the reference level at that frequency).

The summed magnetic field at 30 cm in front of the electrodes was found to be significantly less than for the single phase resistance welder but the reference level was still exceeded by a factor of 3.46 in the plane of the electrodes, compared to 11.93 for the single phase equipment.

However, at a distance of 50 cm away from and in the plane of the electrodes the magnetic field had reduced to 0.8 of the equivalent reference level.

5.5. R7 INVERTER RESISTANCE WELDER

A typical current waveform from the medium frequency inverter welder is shown in Figure 8 and the results are given in Table 3. The measured values correspond to the fundamental switching frequency of 2000Hz and harmonics. Although the absolute magnetic fields were not that high, typically less than 300µT, the reference level at 2000Hz is only 12.5µT and consequently was exceeded at most positions. Even at 5kA at a typical working position at 30cm away from the electrodes the magnetic field was 11µT (2000Hz) and this increased to 19µT (2000Hz) at 15kA.

Only at a distance of 1m away from the electrodes was the magnetic field reduced below the reference level.

5.6. R6 SINGLE PHASE RESISTANCE WELDER WITH KICKLESS CABLE

The results for measurements made along the length of a kickless cable, for a welding current of 15kA are given in Table 5. A typical waveform is similar to that shown in Figure 6.

As expected, for a single phase resistance welder, the results consist of the 50Hz fundamental frequency and harmonics. Although the reference levels are exceeded at a distance of 10 cm away from the cable, by 20 cm the magnetic field is below the reference level, with the exception of the 2m measurement which corresponds to the position of the electrodes.

5.7. MMA WELDING AT 200A

The results from the measurements made on MMA welds are given in Table 6, for the conventional AC transformer (A1), the DC thyristor controlled (A2) and DC inverter (A3) power sources. Typical waveforms from each of these power sources at 200A are given in Figures 9 to 11.

Results for the conventional AC transformer power source, show that the magnetic field is predominantly 50 Hz, with harmonics at 100Hz and 150Hz. Close to the cable at 10cm, the combined exposure was found to exceed the reference levels by a factor of 1.52, but at 20 cm and further away the magnetic field was found to be below the reference level.

For both DC power sources(A2 and A3)the reference levels were not exceeded, even at 10 cm. For the thyristor power source the fundamental frequency was 150Hz and the magnetic field was 37µT. For the DC inverter the greatest magnetic field (15µT) was recorded at about 19kHz, the inverter switching frequency.

5.8. MMA/TIG WELDING, SQUARE WAVE, INVERTER POWER SOURCE

The results from the measurements made with a the AC square wave power source A4 are given in Table 7, and typical waveforms for low (30Hz), medium (145Hz) and high frequency settings (268 Hz) at a nominal setting of 200A are shown in Figure 12.

These results show that in general as the frequency of the output increases for a set current of 200A, the peak- to- peak current is reduced and consequently the magnetic field is also less. However, as frequency increases the reference level is also reduced and consequently at higher frequencies the reference level is exceeded. If the main harmonic components are taken into account the reference level is exceeded by a factor of 5.46 at medium frequency (145 Hz) and by a factor of 7.06 at the highest frequency setting (268 Hz). It is observed that with such square wave outputs the harmonic components are significantly higher than for a sine wave output as would be expected.

5.9. MMA WELDING AT WELDER'S POSITION

The results from the measurements made for a typical MMA welding set up, Figure 5, are given in Table 8, and typical waveforms are shown, as before, in Figures 9 and 12 for the conventional AC transformer (A1) and square wave power (A4) sources respectively.

For the conventional AC power source, as before the fundamental frequency is 50Hz and for this series of tests no significant harmonics were measured. None of the measurements exceeded the reference level of 500µT at 50Hz.

With both welding cables on the floor (position A) , measurements in positions corresponding to the welders head, neck and trunk were very low, as expected. However, when the welding cable was placed in a position corresponding to over the welders shoulder (position B), the magnetic field in positions corresponding to the welders head, neck and trunk, increased considerably, although at 200A the levels were still below the reference levels. The highest magnetic field measured was 298µT at 80cm above the floor, corresponding to the lower part of the trunk. The third set of measurements were made as position B and with a metal plate, conducting the welding current, placed beneath the welder's position to simulate a metal floor, e.g. the deck of a boat (C). The effect of this was found to be to slightly (although not significantly) reduce the magnetic field at the points corresponding to the welders position.

Further measurements were then carried out, substituting the conventional AC with the square wave AC power source in position C. The results are given in Table 8, for a welding current of 200A and a medium frequency (155 Hz) setting. As before for the conventional AC power source, the magnetic field was found to be greatest at positions corresponding to the welders lower trunk. As found previously with this power source the magnetic field at the fundamental frequency is less than for the conventional AC power source, but the harmonic components add a significant contribution to the total magnetic field. Consequently, the total magnetic field was found to exceed the reference levels by a factor of up to 3.75 over the positions corresponding to the head, neck and trunk.

5.10. MIG/MAG WELDING

The results from the measurements made with a MIG/MAG welding power source (A5) are given in Table 9 and typical waveforms for dip, pulse and spray are shown in Figure 13.

With MIG/MAG welding the output current waveform depends on the metal transfer mode. At low current setting the operating mode is known as dip, because the wire dips into the weldpool. This results in rapidly fluctuating changes in the impedance of the welding circuit and consequent changes in the output current. This is clearly seen in Figure 13a. At higher current an open arc is maintained, with small metal drops spraying off the end of the wire and this transfer mode is known as spray transfer, Fig 13c. In advanced welding power sources a third mode of transfer, pulse transfer, can be selected. In this mode the welding current is pulsed between high and low preset values at a frequency depending on the mean current.

The results in Table 9 show that for dip transfer at 150A and spray transfer at 300A the magnetic field at 10cm from the welding cable is low and the reference levels are not exceeded. The fundamental at 88 Hz is the dip transfer frequency and the 53,749Hz component is the inverter switching frequency. With spray transfer the welding current is substantially DC and hence no other significant component could be detected.

With pulse transfer the measured magnetic fields were significantly higher. With pulsed welding the peak current is substantially higher than the mean, in this case 420A and at the pulse frequency of 191 Hz, a field of 170µT was recorded. This is in excess of the reference level by a factor of 1.3 at this frequency. Furthermore as the pulse waveform is substantially square, there are significant harmonic components resulting in the summed magnetic field exceeding the reference level by a factor of 3.2.

6. DISCUSSION

There is a limited number of published papers on magnetic fields from arc and resistance welding equipment. A review of the literature indicates that the ICNIRP reference levels for magnetic fields may be exceeded for both arc and resistance welding. Magnetic fields of up to 400µT for arc welding and about 4000µT for resistance welding have been measured close to the operators body. In arc welding it is common for the operator to be in contact with the welding cable for which fields up to 5000µT have been measured. However, in most cases insufficient experimental details are provided to draw any significant conclusions from the data. A common error is to quote maximum output current, rather than machine setting for the equipment. The magnetic field is made up of many harmonic components but most reported measurements are broadband over the frequency response of the measuring instruments. Detailed measurement of the amplitude and frequency spectrum is required to make a true assessment of the field against the ICNIRP reference levels.

This work has examined the magnetic fields in the vicinity of a number of different types of arc and resistance welding equipment operated using typical welding conditions. The results show that in many cases the magnetic fields are higher than the effective ICNIRP reference levels. In all cases the harmonic components of the waveform made a significant contribution to the magnetic field.

Resistance welding operates at very high currents of the order of many kA and consequently, very high fields have been measured close to the welding electrodes. The highest field recorded was 13.08 mT at 50Hz, 10 cm away from the electrode for a welding current of 15kA. For the single phase welder examined in this study the ICNIRP reference levels are exceeded at a typical operating position of 30 cm away from the electrodes and up to distances of the order of 1m. Measurements close to a kickless cable, as if used to supply a welding head from a remote transformer showed that the magnetic field was less than the reference level at a working distance of 20 cm away from the cable.

Magnetic fields for three phase DC resistance welding equipment are less than for single phase AC equipment, at comparable currents when compared to the reference levels. Although the reference levels were exceeded at a working distance of 30 cm, by 50 cm the field was found to be below the reference level.

Measurements made on the medium frequency inverter resistance welder showed a significant magnetic field component at the switching frequency of 2000Hz and harmonics. Although the absolute field was relatively low at 300µT, the reference level at 2000Hz is only 12.5µT. consequently the reference levels were exceeded at distances of less than 1m from the electrodes.

Arc welding is carried out at much lower currents than resistance welding, but is predominately a manual process. The welder holds the welding torch or electrode in his hand and the cables are often draped over his body to support their weight. Welding can be carried out using either DC or AC depending on the process.

This work has shown that for most arc welding processes the ICNIRP reference levels are not exceeded unless the measurement is taken close to the welding cable, i.e. 10cm. The magnetic field for DC arc welding was found to be typically less than 30% of the effective reference level at 20cm away from the cable. Although for manual welding the reference level would be exceeded at the welder's hand, if only head, neck and trunk are considered, no further investigation would be required provided the welder did not come into close bodily contact with the welding cable. These results suggest that it is not good practice to drape the cable over the shoulder as is often done.

Two recent developments in arc welding equipment, namely AC square wave and pulsed MIG/MAG, produced significant magnetic fields. AC welding is traditionally carried out at 50 Hz with a nominally sine wave output. However, square wave AC provides, by definition, a square wave output, the frequency of which can be adjusted. In the case of the equipment examined, a maximum frequency of about 300Hz could be set. This presents problems in terms of the resultant magnetic field and the reference levels. At 300 Hz the reference level is one sixth of that at 50 Hz and at all frequencies the square wave results in considerable harmonic components. Consequently, the effective reference level was exceeded by a factor of 7 at the highest frequency setting measured and exceeded by 1.5 even at 30Hz, the lowest frequency setting.

Similar problems were found with pulsed MIG/MAG welding, due to the frequency, shape of the waveform and high pulsed currents used. Pulsed MIG/MAG typically operates at 30 Hz to 300Hz and at the 200A setting chosen, the frequency was 191 Hz. Also the peak current measured was 420A. These high currents combined with the wave shape were found to give magnetic fields approximately 3 times in excess of the effective reference level at 20cm.

These results emphasise the need to consider the harmonic components of the magnetic fields produced by arc and resistance welding equipment. Comparisons to the reference levels must take into account the individual frequency components of the magnetic fields. These harmonic components arise from power frequency circuits in conventional equipment, switching frequencies in inverter equipment and process settings e.g. pulsed waveforms in arc welding.

The results show that in many cases the magnetic fields are higher than the ICNIRP reference levels. A more detailed investigation of these magnetic fields is required, taking into account how the equipment may be used, and it is recommended that the data obtained during this project is further analysed using modelling techniques to assess whether the ICNIRP basic restrictions are also exceeded.

7. CONCLUSIONS

From a literature review and measurements made of magnetic fields in the vicinity of resistance and arc welding equipment the following conclusions are drawn.

1. A review of the literature indicates that ICNIRP reference levels for magnetic fields may be exceeded for both arc and resistance welding. However, in most cases a lack of experimental details and broadband measurements make it difficult to draw any significant conclusions from the data.
2. The magnetic field is made up of many harmonic components which need to be taken into account when making assessments against ICNIRP reference levels.
3. For resistance welding equipment the ICNIRP reference levels are exceeded in most cases at the position that the welder would normally stand, i.e. 30cm from the electrodes.
4. For single phase and medium frequency inverter resistance welding equipment examined at a welding current of 15kA the reference levels are unlikely to be exceeded at distances greater than 100cm from the electrodes.
5. The magnetic field around three phase equipment is generally less and the reference levels are unlikely to be exceeded at distances greater than 50 cm for the equipment examined at a typical welding current of 15kA.
6. The magnetic field around a kickless resistance welding cable was found to be below the effective reference level at distances of 20cm or more.
7. Magnetic fields from arc welding are in general below the reference levels at distances of 20cm or greater, with some exceptions. It is therefore recommended that welders do not come into close proximity with welding cables wherever possible. Draping the cables over the shoulder or around the body should be avoided.
8. Recent developments in arc welding equipment, namely AC square wave and pulsed MIG/MAG, develop significantly higher magnetic fields and the effective reference levels may be exceeded.
9. Further investigation is required to assess whether the ICNIRP basic restrictions are also exceeded.

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9. REFERENCES

1. **Allen et al,** *Review of occupational exposure to optical radiation and electric and magnetic fields with regard to the proposed CEC Physical Agents Directive.* NRPB-R265, 1994
2. **ARO,** *Electromagnetic fields and resistance welding,* Preliminary commercial publication.
3. **AWS,** Pacemakers and welding, American Welding Society (AWS), Fact sheet No. 16, 1998.
4. **AWS,** E*lectric and magnetic fields (EMF),* American Welding Society (AWS), Fact sheet No. 17, 1998.
5. **Bowman et al,** E*xposure to extremely low frequency (ELF) electromagnetic fields in occupations with elevated leukemia rates,* Appl. Ind. Hyg. Vol 3, No 6, 1988.
6. **Cooper TG,** *Occupational exposure to electric and magnetic fields in the context of the ICNIRP guidelines,* NRPB-W24
7. **Chadwick PJ,** *Occupational exposure to electromagnetic fields: Practical application of NRPB guidance,* NRPB-R301, 1998.
8. **Doebbelin R et al.** *Measurement and evaluation of pulsating environmental magnetic fields by the example of resistance welding installations.* Int. Conf. on electromagnetic compatibility, China, 2002.
9. **Floderus B,** *Resistance welding, magnetic field exposure and cancer incidence (title of study- not published),* Institute of environmental medicine at the Karolinska Institute, Stockholm, Sweden, 1999 (www.sandshark.kib.se)
10. **Feychting M, et al,** Occupational and residual magnetic field exposure and leukemia and central nervous system tumors, Epidemiology, vol 8, 1997.
11. **HVGB,** *BGR B11 electromagnetic fields,* English translation 29 June 2001
12. **IPCS,** *Magnetic Fields,* Health and safety guide No. 27, WHO 1989.
13. **Lovsund P et al,** *ELF magnetic fields in electro-steel and welding industries.* Radio Sci. 1982, 17(5S)
14. **Nadeem M et al,** *Dosimetry of human body exposed to magnetic field of point welding machine,* Bioelectromagnetics (to be published)
15. **NIOSH Fact sheet,** *EMFs in the workplace,* DHHS (NIOSH) Publication No. 96-129.
16. **Silny et al,** *Electromagnetic environmental compatibility of resistance spot welding installations,* welding and cutting Vol 53, No 5, 2001.
17. **Skotte JH and Hjollund HI,** *Exposure of welders and other metal workers to ELF magnetic fields,* Bioelectromagnetics 18:470-477 (1997)
18. **Stern RM,** *Cancer incidence among welders: possible effects of exposure to extremely low frequency electromagnetic radiation and to welding fumes.* Environmental Health Perspective 76, 1987
19. **Stuchly MA and Lecuyer DW,** *Exposure to electromagnetic fields in arc welding,* Health Physics, Vol 56, No. 3, 1989
20. **Story M,** *Magnetic fields, a cautionary tale,* CSIRO memo to staff (www.electric-words.com)
21. **Weman K,** *Health hazards caused by electromagnetic fields during welding,* Svetsaren, Vol 48, 1994.

TWI ENDORSEMENT

The report has been reviewed in accordance with TWI policy.

Project Leader ……………………………….
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Table 1 Magnetic field measurements (µT) for R4 – single phase resistance welder

Reference levels (µT)				***500.0***	***250.0***	***166.7***	***100.0***	***71.4***	***55.6***	***45.5***	***38.5***	***33.3***	***29.4***	***26.3***	***23.8***	***21.7***
Axis	***Current***	***Distance***	$\sum \frac{B_n}{R_n}$	***Frequency component (Hz)***												
	(kA)	***(cm)***		***50***	***100***	***150***	***250***	***350***	***450***	***550***	***650***	***750***	***850***	***950***	***1050***	***1150***
X	15	10														
X	15	20	52.82	9874		1221	840	437		72	29	64	71	58	34	20
X	15	50	12.10	2148		325	172	93	46	18	7	14	15	13		
X	15	100	2.26	484		67	37	21	7				3			
Y	15	50	3.37	705		102	40	32	15	5		4				
Y	15	20	7.88	1475		203	112	63	31	12		7	10	9		
Y	15	0	11.94	1771		242	133	75	37	15	4	9	12	10	8	45
Y	15	-20	6.66	1373		188	102	58	28	11		7				
Y	15	-50	3.24	619		86	44	26	13	5		3	4	3		
Y	15	-100	0.75	189			26	8								
Z	15	10	61.23	13,080		1700	928	507	275	121	34					
Z	15	20	14.81	4399		586	250									
Z	15	50	3.64	689		93	48	29	15	6			4	4	3	
Z	15	100	0.69	156		21	25									
Y	5	50	0.41	207												
Y	5	20	3.88	438		271	57	31	21							
Y	5	0	4.89	518	25	317	67	51	26							
Y	5	-20	4.09	408		249	53	40	20	15						
Y	5	-50	0.37	186												

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Table 2 Magnetic field measurements (μT) for R4 – single phase resistance welder, welding test plates

Reference levels (μT)		***500.0***	***250.0***	***166.7***	***100.0***	***71.4***	***55.6***	***45.5***	***38.5***
Test plates ***10kA at 20cm, Z direction***	$\sum \frac{B_n}{R_n}$	***Frequency component (Hz)***							
		50	***100***	***150***	***250***	***350***	***450***	***550***	***650***
Short circuit	13.41	1170		861	223	49	89	49	12
Test coupon	3.54	582	198	56	12	27	17	5	13
Plate, weld 1	4.70	917	282	84	16	30	16	5	10
Plate, weld 2	4.93	997	285	98	16	24	19	5	10
Plate, weld 3	4.44	861	264	81	15	25	17	5	10

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Table 3 Magnetic field measurements (µT) for R10 – three phase resistance welder

Reference levels (µT)				***250.0***	***166.7***	***83.3***	***55.6***	***41.7***	***33.3***	***27.8***	***26.3***	***23.8***	***20.8***	***18.5***
Axis	***Current (kA)***	***Distance (cm)***	$\sum \frac{B_n}{R_n}$	***Frequency component (Hz)***										
				100	***150***	***300***	***450***	***600***	***750***	***900***	***950***	***1050***	***1200***	***1350***
X	15	10	0											
X	15	20	19.78		1605	307	154	78	53		6			
X	15	50	4.21		298	54	30	15	10	6		5	3	
X	15	100	0.49		59	11								
Y	15	50	0.72		75	12	7							
Y	15	20	4.19	29	300	54	30	15	10	6		5		
Y	15	0	3.28	29	300	37	20	10	6	4				
Y	15	-20	1.84		157	31	10	8	5					
Y	15	-50	0.43		53		6							
Z	15	10												
Z	15	20	6.80		480	91	48	23	16	10		8	5	
Z	15	50	0.80		80	15	8							
Z	15	100	0.10		17									
Y	5	50	0.50		59	12								
Y	5	20	1.65	36	152	23	11	5						
Y	5	0	2.30	49	204	32	14	5	4					
Y	5	-20	1.69	40	158	22	11	5						
Y	5	-50	0.16		27									

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Table 4 Magnetic field measurements (µT) for R7 – inverter resistance welder

Reference levels (µT)				***12.5***	***6.3***	***4.2***	***3.1***	***2.5***	***2.1***	***1.8***	***1.6***	***1.4***	***1.3***	***1.1***	***1.0***	***1.0***
Axis	***Current***	***Distance***	$\sum \frac{B_n}{R_n}$	***Frequency component (Hz)***												
	(kA)	***(cm)***		***2000***	***4000***	***6000***	***8000***	***10000***	***12000***	***14000***	***16000***	***18000***	***20000***	***22000***	***24000***	***26000***
X	15	10	139.92	723	181	7	47	26	4	16			8	4		5
X	15	20	37.6	211	54		13	8		5	3					
X	15	50	2.96	25	6											
X	15	100	0.24	3												
Y	15	50	0.48	6												
Y	15	20	1.52	13	3											
Y	15	0	22.64	19	9		4						23			
Y	15	-20	7.2	24	11		6	4								
Y	15	-50	1.76	12	5											
Z	15	10	84.56	267	135	17	51	53								
Z	15	20	31.76	97	51	6	20	20								
Z	15	50	2.4	14	8											
Z	15	100														
Y	5	50														
Y	5	20	1.28	8	4											
Y	5	0	1.68	11	5											
Y	5	-20	1.28	8	4											
Y	5	-50	0													

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Table 5 Magnetic field measurements (μT) for R6 – single phase resistance welder with kickless cable

Reference levels (μT)				*500.0*	*250.0*	*166.7*	*100.0*	*71.4*	*55.6*	*45.5*	*38.5*	*33.3*
Position	*Current*	*Distance*	$\sum \frac{B_n}{R_n}$	*Frequency component (Hz)*								
(m)	*(kA)*	*(cm)*		*50*	*100*	*150*	*250*	*350*	*450*	*550*	*650*	*750*
1	15	10	1.49	210		65	30	10		5	5	
1	15	20	0.62	131		36	14					
1	15	50	0.4	82		21	11					
1.5	15	10	2.37	390		94	40	14		7	6	4
1.5	15	20	0.57	130		33	11					
1.5	15	50										
2	15	10	25.44	4531		1148	435	104	44	53	42	21
2	15	10	6.26	1166		263	107	33	10	15	12	
2	15	50	0.55	128		31	11					

Table 6 Magnetic field measurements (μT) for MMA welding at 200A, right angle bend in cable

Equipment	*AC conventional*				*DC thyristor*		*DC inverter*			*Squarewave - medium frequency*						
Distance from cable (cm)	*50 Hz*	*100 Hz*	*150 Hz*	$\sum \frac{B_n}{R_n}$	*150 Hz*	$\sum \frac{B_n}{R_n}$	*1670 Hz*	*19175 Hz*	$\sum \frac{B_n}{R_n}$	*145 Hz*	*290 Hz*	*435 Hz*	*580 Hz*	*870 Hz*	*1160 Hz*	$\sum \frac{B_n}{R_n}$
10	644	32	18	1.52	37	0.22	5	15	0.49	352	95	61	54	27	15	7.09
20	337			0.67	22	0.13	7	9	0.29	202	57	35	34	18	10	4.32
50	225			0.45		0.00			0.00	92	25	15	15	7		1.68

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Table 7 Magnetic field measurements (µT) for MMA welding at 200A, AC square wave power source

Low frequency setting				*Medium frequency setting*				*High frequency setting*			
Frequency component (Hz)	*B (µT)*	*Reference (µT)*	$\frac{B_n}{R_n}$	*Frequency component (Hz)*	*B (µT)*	*Reference (µT)*	$\frac{B_n}{R_n}$	*Frequency component (Hz)*	*B (µT)*	*Reference (µT)*	$\frac{B_n}{R_n}$
30	536	833.33	0.64	145	352	172.41	2.04	268	316	93.28	3.39
60	172	416.67	0.41	290	95	86.21	1.10	536	32	46.64	0.69
90	76	277.78	0.27	435	61	57.47	1.06	806	74	31.02	2.39
120	38	208.33	0.18	580	54	43.10	1.25	1074	14	23.28	0.60
		$\sum \frac{B_n}{R_n}$	1.51			$\sum \frac{B_n}{R_n}$	5.46			$\sum \frac{B_n}{R_n}$	7.06

Table 8 Magnetic field measurements (µT) for MMA welding at 200A, different configuration

Power source	*AC conventional (µT)*			*AC Squarewave (µT)*						
Configuration	***A***	***B***	***C***	***C***						
Height above ground (cm)	***50 Hz***	***50 Hz***	***50 Hz***	***155 Hz***	***310 Hz***	***465 Hz***	***620 Hz***	***775 Hz***	***930 Hz***	$\sum \frac{B_n}{R_n}$
180		54	51	26	7					0.25
160		101	88	53	9	12	6	4		0.94
140		165	150	100	17	22	10	6		1.69
120		222	192	137	24	32	15	10	8	2.74
100	57	276	235	175	30	40	19	12	14	3.59
80	101	298	251	173	31	42	20	13	16	3.75
Reference levels (µT)	500	500	500	161	80	53	40	32	27	

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Table 9 Magnetic field measurements (μT) for MIG/MAG welding

Dip, 150A				*Pulse, 200A*				*Spray, 300A*			
Frequency component (Hz)	***B (μT)***	***Reference (μT)***	$\frac{B_n}{R_n}$	***Frequency component (Hz)***	***B (μT)***	***Reference (μT)***	$\frac{B_n}{R_n}$	***Frequency component (Hz)***	***B (μT)***	***Reference (μT)***	$\frac{B_n}{R_n}$
88	56	284.09	0.20	191	170	130.89	1.30				
				382	61	65.45	0.93				
				573	12	43.63	0.28				
				764	12	32.72	0.37				
				955	3	26.18	0.11				
53749	5	30.70	0.16	53749	5	30.70	0.16	53749	7	30.70	0.23
		$\sum \frac{B_n}{R_n}$	0.36	820		$\sum \frac{B_n}{R_n}$	3.15			$\sum \frac{B_n}{R_n}$	0.23

If $\sum \frac{B_n}{R_n} > 1$ the effective ICNIRP reference level has been exceeded.

Figure 1 Magnetic field sensor

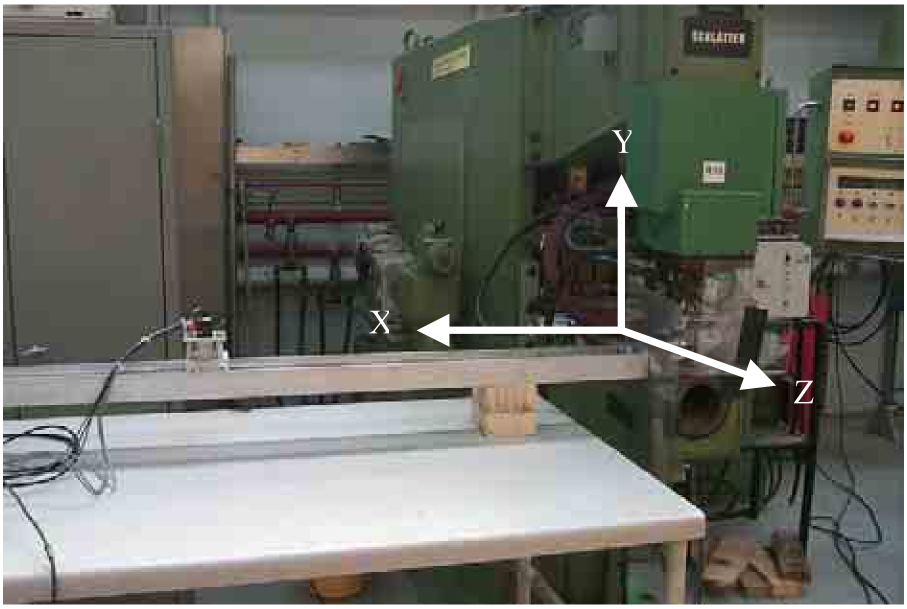
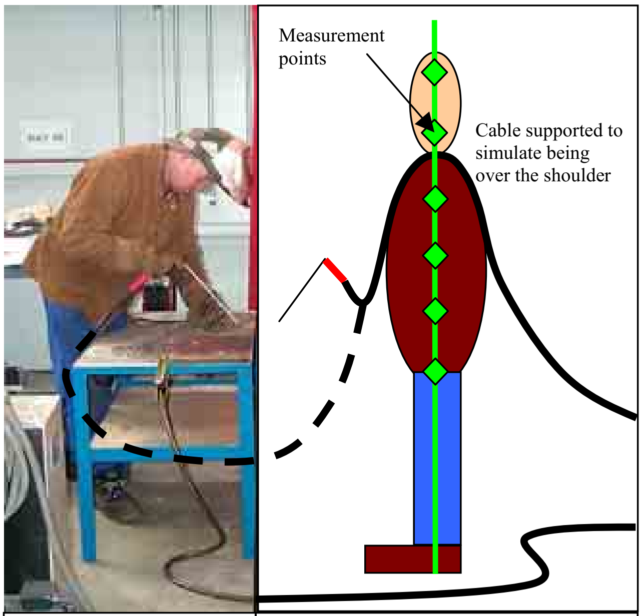


Figure 2 Measurements being taken on a resistance welding machine

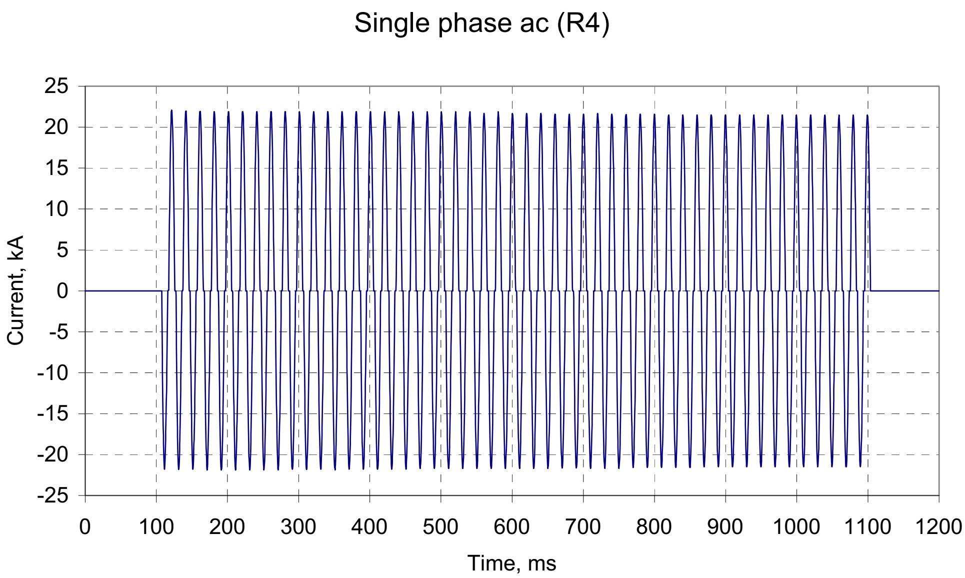
Figure 3 Measurements on the kickless cable

Figure 4 Measurements on arc welding cable

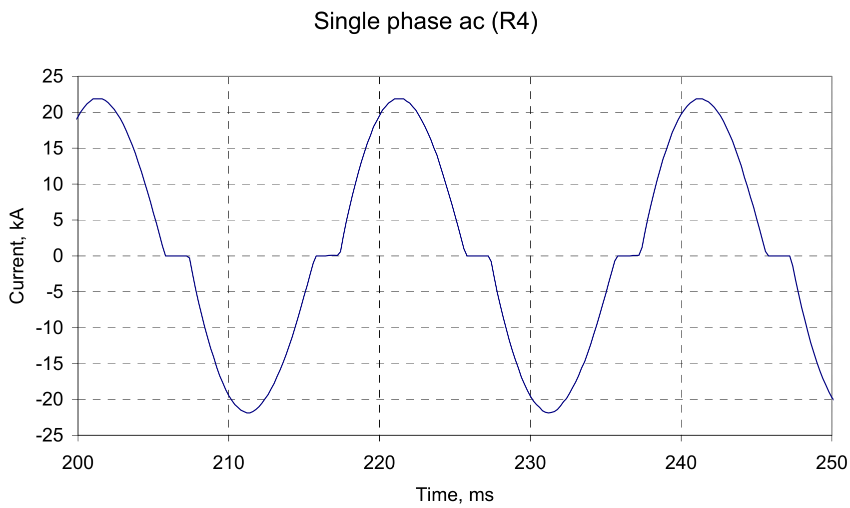


Welder on one side of bench	Measurement set up on other side of bench, with cable supports

Figure 5 Arc welding set up

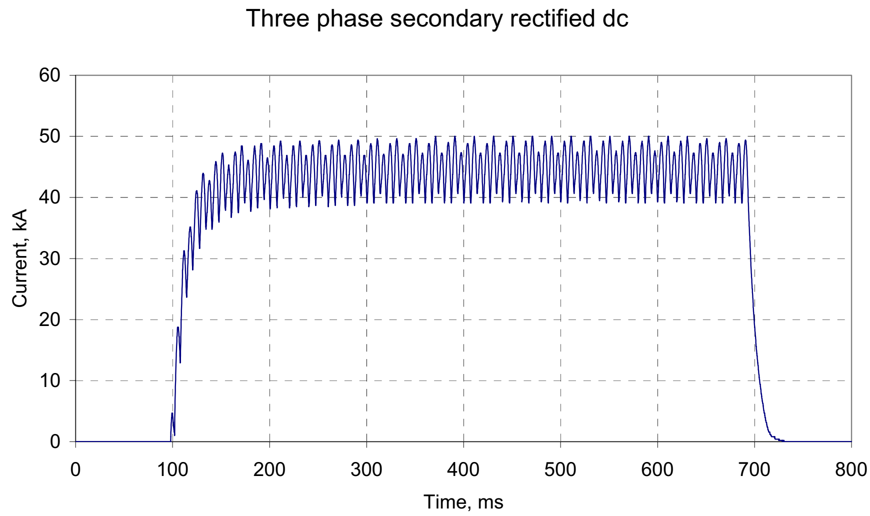


a)

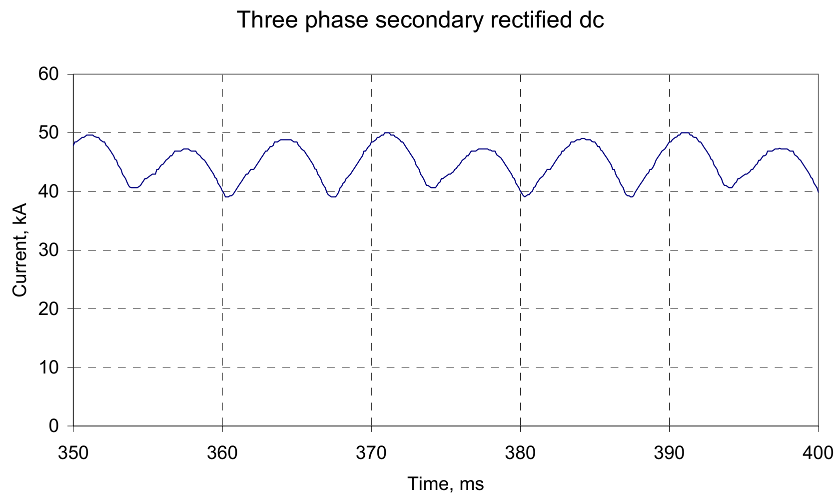


b)

Figure 6 Single phase resistance welding equipment (R4) waveforms
a) Full cycle, b) Detail

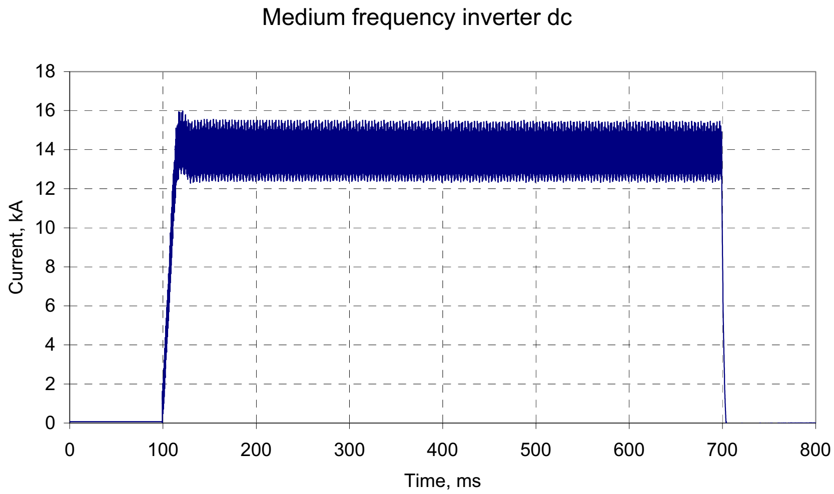


a)

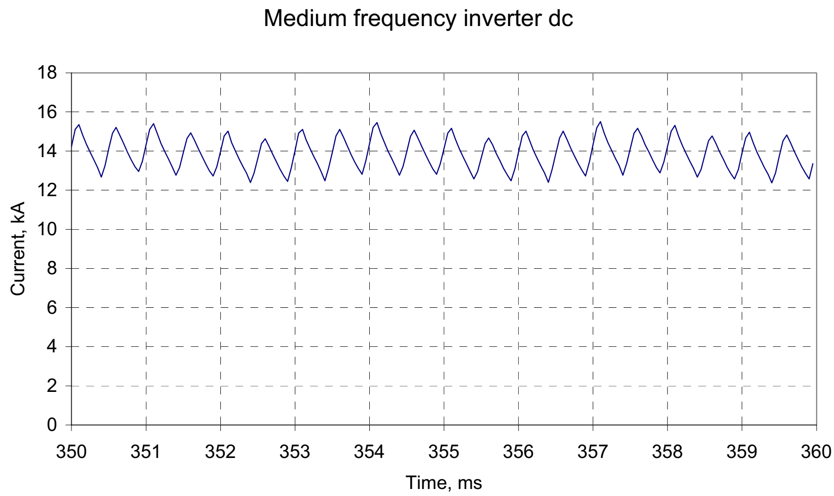


b)

Figure 7 Three phase resistance welding equipment (R10) waveforms
a) Full cycle, b) Detail



a)



b)

Figure 8 Medium frequency inventer welding equipment (R7) waveforms
a) Full cycle b) Detail

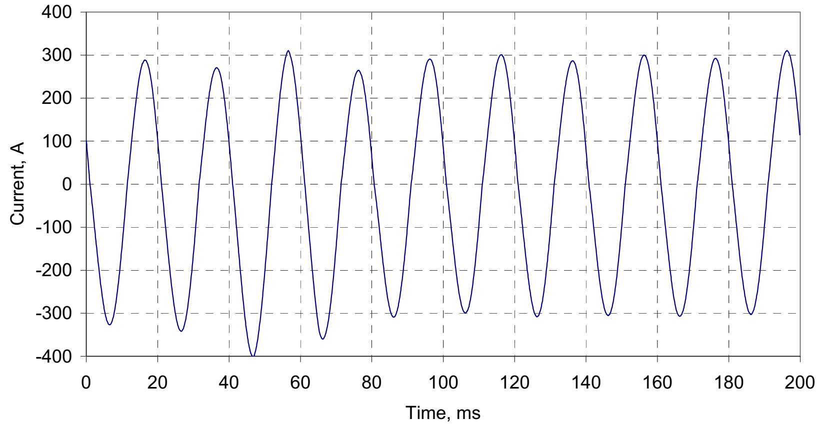


Figure 9 AC conventional transformer waveform

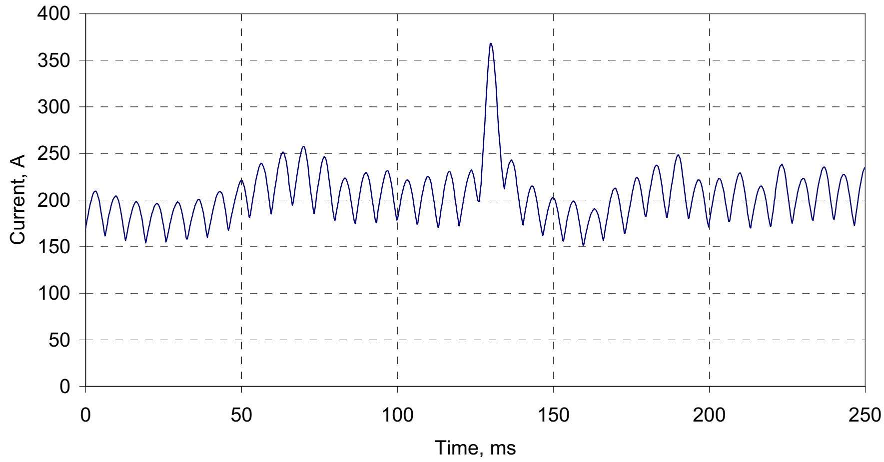


Figure 10 DC thyrister waveform

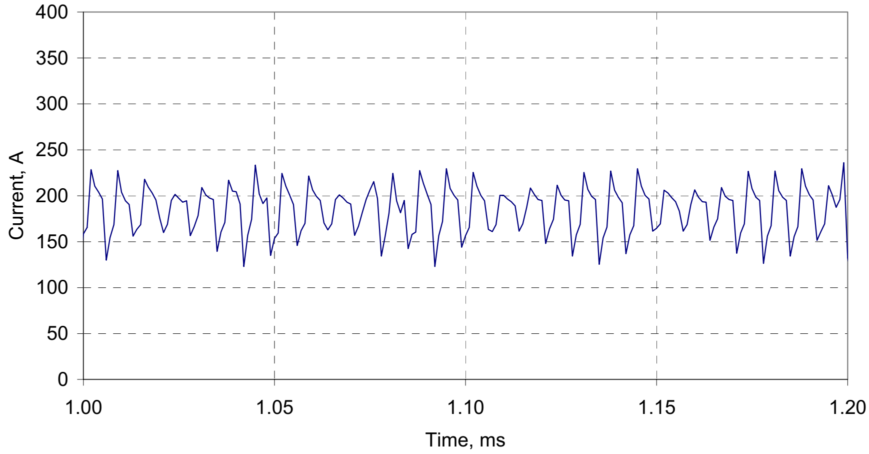
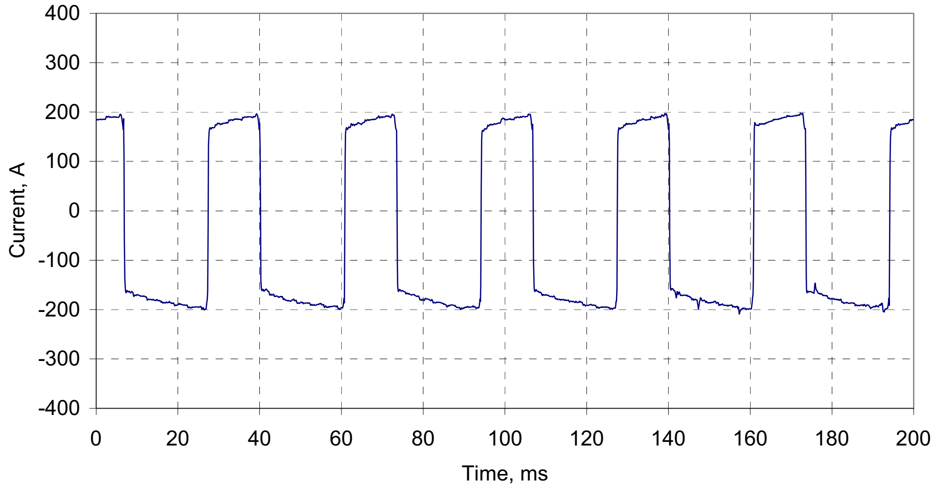
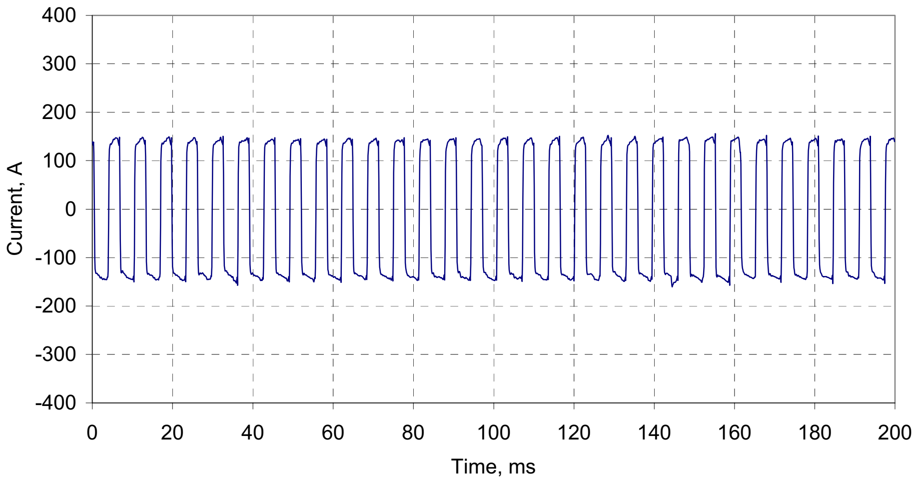


Figure 11 DC inverter waveform

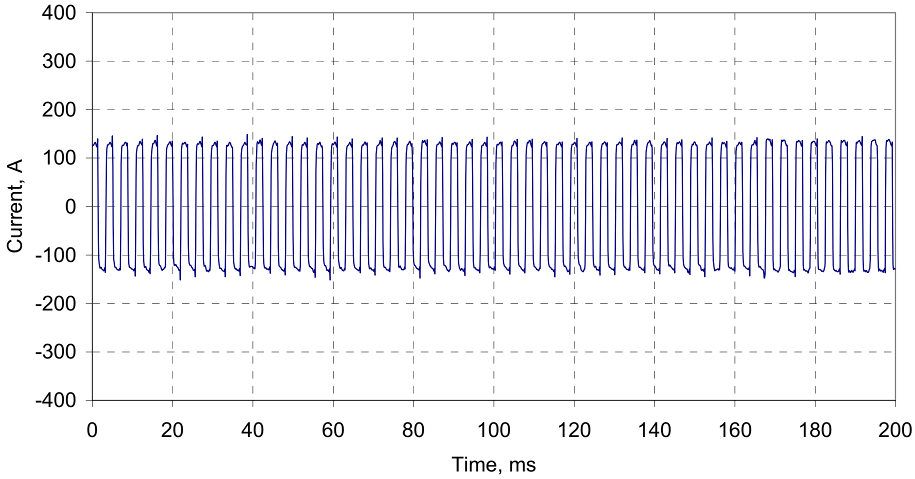


a)



b)

Figure 12 Square wave AC waveforms
a) Minimum frequency b) Medium frequency



c)

Figure 12 contd. Square wave AC waveforms
c) Maximum frequency

Appendix A

ICNIRP Guidelines

GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC, AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz)

International Commission on Non-Ionizing Radiation Protection*†

Table 6. Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).[a]

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

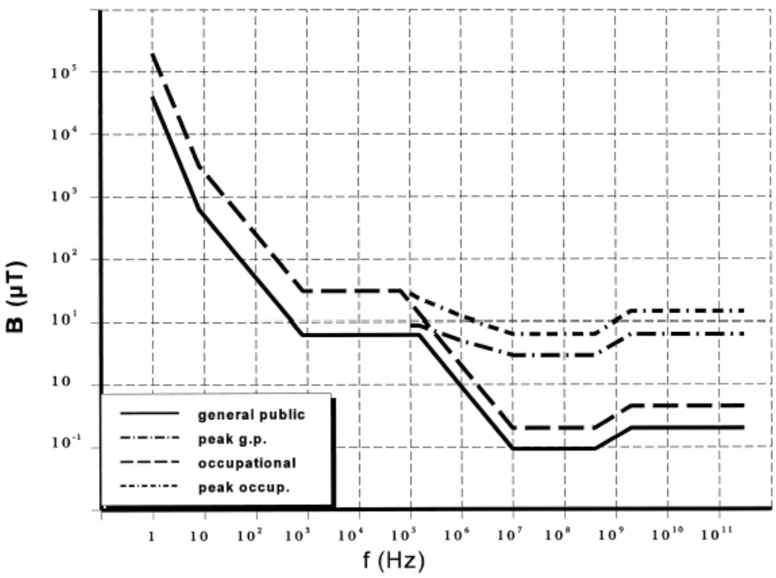


Fig. 2. Reference levels for exposure to time varying magnetic fields (compare Tables 6 and 7).

Appendix B

Data Analysis

Each of the data files was subject to the following analysis stages:

- In the first instance the data file was loaded into memory and then each of the sensors was checked to see if the maximum or minimum input voltages for the data acquisition card had been exceeded. Should this occur, the data for that sensor would be invalid as well as the resultant magnetic field calculated from all three sensors, i.e. if the x-axis Hall sensor was saturated then the resultant field for all three of the Hall sensors would also be invalid. In the event of one of the magnetometer, Hall or coil sensors being saturated data analysis was terminated for that sensor and a note was recorded in the log file *AnalysisLog.txt*.

- The next step in the data processing was to convert the measured voltages to magnetic field using data from the calibration of each of the sensors prior to initial magnetic inspections. In the case of the coil sensors this was slightly more complex as they measure the rate of change of magnetic field (Lenz's law of electromagnetic induction). This requires the integration of the temporal data to give the magnetic field.

- Having converted the temporal voltages into magnetic field a Fast Fourier Transform was used to calculate the magnitude of the magnetic field in the frequency domain. For each of the three different sensors a frequency cut-off was then applied, based on their operating bandwidth. This was 3kHz, 10kHz and 100kHz for the magnetometers, Hall sensors and coil sensors respectively.

- The final stage of the data analysis was to calculate the resultant magnetic field by summing the three orthogonal axes for each sensor in quadrature. At the same time the magnetic field error for each sensor and the resultant error calculated. Having completed the analysis the resultant field and the associated resultant error were saved to a data file for each frequency in the frequency spectrum.

Even after this first phase of analysis, and the data reduction associated with it, there was still a large quantity of data generated. As a result a second analysis phase was instigated after an initial review of the phase one data. The second phase analysis was performed on the data generated from the phase one analysis and comprised the following steps:

- The phase one data was loaded into memory and the ICNIRP reference levels were calculated for the frequency spectrum.

- If the data was measured using the coil sensors then the magnitude of the field at each frequency was compared to ten percent of the ICNIRP reference level for that frequency. Any frequency where the magnitude exceeded this level was recorded along with the resultant error.

- If the data was measured using the magnetometers and Hall sensors then the maximum magnitude of the two sensors at each frequency was compared to ten percent of the ICNIRP reference level for that frequency. Any frequency where the magnitude exceeded this level was recorded along with the resultant error.

- Having completed the phase two analysis the resultant field and field error were saved to a data file for each frequency at which the magnitude exceeded ten percent of the ICNIRP reference level. If at no point ten percent of the ICNIRP reference level was exceeded then a data file was not saved and a note was recorded in the phase two analysis log file, *Analysis.txt*.

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